Chapter 2. CONCEPTUAL MODELS

A. Introduction

Conceptual models are visual or narrative summaries that describe the important components of an ecosystem and the interactions among them. Conceptual models help us develop a "mental picture," that is often difficult to convey in words. Models also provide scientists and managers from different disciplines a common view of landscapes and ecosystems and provide an objective hierarchical framework for identifying attributes to monitor.

The purpose of this chapter is to explain our understanding of how drivers of change and ecological interactions affect selected natural resource components and processes of SWAN parks. The models serve as pictorial illustrations of the conceptual foundation for monitoring presented in chapter 1 and support the identification and selection of ecological vital signs for monitoring.

Developing conceptual models helps us gain an understanding of how park ecosystems work and promotes communication among scientists and park managers. For example, during a scoping workshop that focused on physical landscape drivers, participants exchanged ideas about how climate and landforms interact to influence ecosystem processes in the network. By illustrating the perceived relationships in diagram form, the participants reached a better understanding of the range of physical forces, how they operate, and how they influence biological communities.

We prepared conceptual models of coastal, freshwater, and terrestrial subsystems for each scoping workshop. Model development required extensive literature review and consultation with research scientists and landscape ecologists familiar with subarctic ecosystems. In some cases, published or unpublished models of ecosystems similar to Southwestern Alaska were used. In the scoping workshop notebooks, conceptual models are presented in a hierarchical format focusing on the broadest view of the network and then zooming into subcomponents. The broad perspective is useful to illustrate geoclimatic setting and regional scale processes responsible for the formation of landforms. A narrower perspective, such as a trophic food web, is useful to illustrate the processes responsible for the formation of habitat types and ecological functions such as primary and secondary production. Specific models produced for scoping workshops included:

- Physical forces and energy flow—to describe the environmental context and most important abiotic factors influencing the subsystem;

- Trophic interactions (i.e., food webs)—to identify the "cast of players" in each subsystem, clearly identify the food base for each level of the subsystem, and to see the connections between producers, consumers, and decomposers.

- Habitat types—to identify the most widely recognized types of habitats within each subsystem (e.g., lake types, intertidal communities, vegetation associations).

- Human activities—to characterize the human activities of current importance in the subsystem and identify activities of future concern.

Throughout the scoping workshops and other phases of planning, network staff consulted these models to examine how processes may be linked across space and time. In some cases, workshop participants refined or created new ecosystem models. Models were also used to help formulate specific testable questions to be answered through long-term monitoring (chapter 1, section E, monitoring goals, objectives, and questions).

Models created for scoping workshops played an important role in the ongoing process of building the holistic models presented here. However, because coastal, freshwater, and terrestrial ecosystems in the SWAN are tightly linked by geoclimatic forces, energy exchange, and biotic processes, it would be redundant to repeat each set of models three times. A common view of all three major systems facilitates understanding of the most important drivers of change in Southwest Alaska Network ecosystems.

Common themes about the drivers emerged and were reinforced throughout the workshop series. Workshop participants and researchers who have expert knowledge of subarctic landscapes repeatedly ranked climate/landform, landscape-scale disturbance, biotic interactions, and human activities as the four interactive drivers having the greatest relative impact on network parks. A holistic model (figure 2-1) depicts these four major drivers that affect the network at the landscape-scale. They control the structure and processes important in the primary subsystems (coastal, freshwater, and terrestrial). Any number of more detailed models for various components or processes can be nested within this holistic model, without losing the broad view. The holistic model provides perspective and a forum for discussion of the relative strength of various forces acting in this network.

In this chapter, we present a nested set of models for the SWAN that depicts geoclimatic setting, ecosystem interactions, and interactive drivers of change. Understanding the influence and magnitude of drivers of change, the collective influence of multiple drivers, the ecological consequences of the changes, and the feedbacks between ecosystems and their physical environments are all crucial to developing strategies for long-term monitoring.

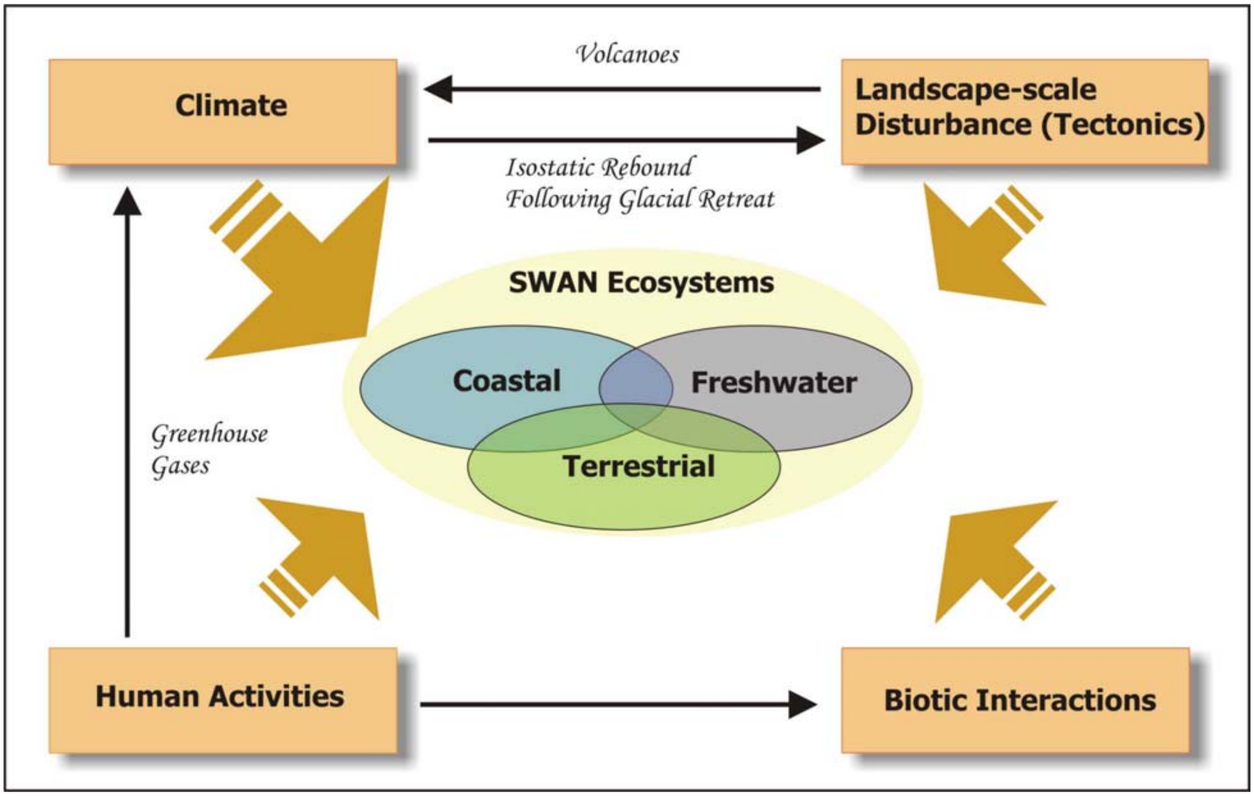
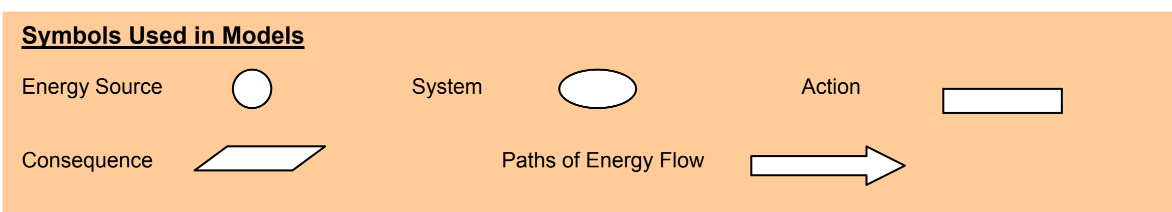


Figure 2-1. Holistic model. Major driving forces shaping park ecosystems are climate, landscape-scale disturbance, biotic interactions, and human activities. The model depicts the close linkages between the primary subsystems (coastal, freshwater, terrestrial) of park ecosystems and feedbacks between the drivers. Drivers can act independently and interactively. For example, volcanic eruptions are a tectonic disturbance that can lower air temperatures.



B. Landscape Drivers of Change

1. Climate and landform

Climate is considered to be the most important broad-scale factor influencing ecosystems. In Alaska, climate patterns reflect latitude, surrounding oceans, topography, and the interactions of these with global circulation (Simpson et al. 2002). Because climate involves patterns of temperature and precipitation, the hydrologic cycle is the primary ecosystem driver, impacting both aquatic and terrestrial plants and animal communities, as well as the physical processes within the landscape. Understanding the patterns of precipitation, flow, and storage of water is therefore central to understanding climate as a driving force in SWAN ecosystems.

Southwest Alaska Network parks are aligned along the Northern Gulf of Alaska where the climate is dominated by maritime influences. Characteristics of this maritime climate include low annual temperature flux, a relatively warm average annual temperature (above freezing), and high amounts of precipitation. Important features of the climate-hydrological cycle in network parks include winter storms generated by the Aleutian Low, summer storms generated in the Bering Sea, the presence of glaciers, and seasonal snow cover generally persisting from October to April—more than half the year.

Maritime influences interact with topography to create patterns of precipitation and wind. Topography in network parks is dominated by steep mountains built as the Pacific Plate slides under the North American Plate. This creates mountains that rise abruptly from the ocean in the path of the prevailing winds (figure 2-3) and results in orographic precipitation on the windward side of the mountains and rain shadows on the leeward side.

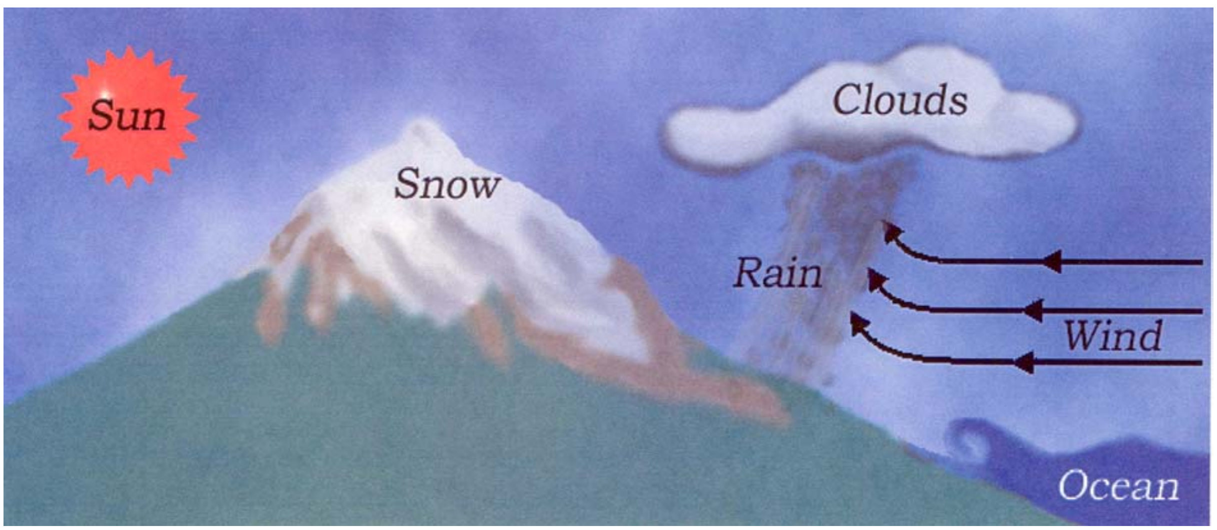


Figure 2-3. Physical interaction between topography and maritime air masses along the Northern Gulf of Alaska.

Coastal mountain ranges along the Northern Gulf of Alaska are distinguished by being one of the snowiest places on the planet. Coastal areas of Katmai, Kenai Fjords, and Lake Clark have the right combination of winter precipitation and oceanic air currents, as well as steep temperature and elevational gradients to generate impressive snowfall. The interplay among wind, topography, and snowfall creates a heterogeneous snow distribution. This affects vegetation and biotic processes by determining the local abundance of water and growing season length.

Climate interacts with landform to play a fundamental role in governing ecosystems by influencing four major processes:

Microclimate

Landform affects temperature and precipitation via elevation, and radiation via topographic position relative to incident insolation.

Topographic control of water inputs to lakes

Topographic position of lakes within a drainage system has a large influence on the relative importance of precipitation as compared to groundwater flow as inputs to lakes. This, in turn, has implications for water chemistry and biological processes affected by water chemistry.

Wind-mediated disturbances

Many disturbance agents are influenced by terrain as it interacts with wind. For example, wind throw is more common in mountain passes and on high windward slopes.

Landform-mediated disturbances

Other disturbances are mediated directly by landform and slope position. For example, susceptibility to small-scale landslides or slumping depends on terrain shape (e.g., slope concavity).

Long-term weather data from representative sites in the network region demonstrate the annual climate patterns that result from these interactions between the dominant Aleutian Low winter storm system and network landforms. Seward, located on the windward side of the prevailing winter storm track, is wet and warm, and receives most of its precipitation in winter months (figure 2-4). Port Alsworth, located on Lake Clark, is cold and dry and has a continental climate similar to sites in Interior Alaska.

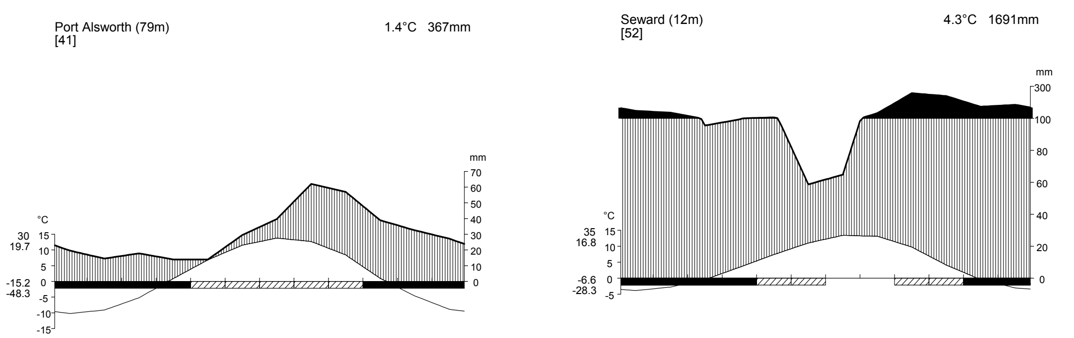


Figure 2-4. Walter Climate Charts (Walter 1963) depicting climatic variation in the SWAN. [Charts show long-term averages for precipitation and temperature for each month of the year (x-axis).] Note the warm average annual temperature and high amounts of precipitation at Seward, Alaska, located near the northern boundary of Kenai Fjords National Park. The drop in precipitation that occurs in summer reflects weakening of the Arctic High and a shift in storm track direction, such that Seward is in the lee of summer storms. In contrast, Port Alsworth, on the west side of Lake Clark National Park and Preserve, is in the rain shadow of the Chigmit Mountains, and has a cold, dry climate similar to many other sites in Interior Alaska.

While the Aleutian Low storm track is the predominant climate driver in the network throughout most of the year, in summer, the Arctic High retreats, the location of the low pressure systems shifts, and the storm track changes direction (Simpson et al. submitted). Instead of moving SE to NW, the storms now originate in the west, and move east. Within the SWAN, this shift in storm track direction changes what is leeward and windward and explains the somewhat surprising drop in precipitation that occurs in Seward in June and July. The Alaska Peninsula appears to be located at the fulcrum of this winter-summer storm track shift. This is an important feature of SWAN climate and explains much of the variation in climate among sites in the network, particularly with respect to the timing and amount of precipitation.

Because climate is such an important determinant of the ecological setting, changes in climate act as drivers of ecological change. Climate changes occur at multiple scales of space and time. At very long time scales, the Southwest Alaska Network is being affected by post-Pleistocene warming. The entire network was glaciated during the Pleistocene (Hamilton and Nelson 1989). The current pattern of glacier distribution in network parks reflects widespread retreat during the Holocene (the most recent geologic period). At Aniakchak, located at the southern end of the network, there are no glaciers. Farther north in Katmai, mountain glaciers are present. Lake Clark includes both mountain and valley glaciers. Kenai Fjords has large icefields and numerous valley and mountain glaciers.

At shorter time scales, the climate of the region is affected by primarily oceanic factors, such as the Pacific Decadal Oscillation (PDO) and El Nino/Southern Oscillation (ENSO). The PDO and ENSO are patterns in sea surface temperature driven by changes in the tropics. PDO events have a strong influence on precipitation patterns. During positive PDO events, winter storm tracks that would normally go to Southeast Alaska are diverted into the Cook Inlet region, enhancing precipitation in Coastal Central Alaska, including much of the network (Simpson et al. 2002). ENSO events involve mainly temperature; and their effects can be widespread, influencing conditions in Interior Alaska, as well as coastal areas.

2. Landscape-scale Natural Disturbances

Natural disturbances are important drivers of change (chapter 1) and are defined as any relatively discrete events in space and time that disrupt ecosystem, community, or population structure and change resources, substrate, or the physical environment (White and Pickett 1985). The key parts of this definition are that disturbances are *discrete* in time, in contrast to chronic stress or background environmental variability; and that they cause a notable change (a *perturbation*) in the state of the system.

We examined historical, geomorphologic, hydrologic, and ecological research to develop an integrated understanding of how natural disturbances have shaped landforms and ecological processes. In addition, paleo-ecological studies recently initiated by the network (2003-2005) will broaden our understanding of how current ecological characteristics developed. Alaska ecosystems, especially those of Southwestern Alaska, are shaped and maintained by disturbances. Infrequent large-scale disturbances (volcanic eruptions, earthquakes, tsunamis) and more frequent smaller-scale disturbances (insect outbreaks, floods, and landslides) create and maintain a shifting mosaic of landscape patterns (figure 2-5).

Southwest Alaska Network parks lie on the border where two continental plates meet. Network parks are on the outer edge of the North American Plate, where it borders the Pacific Plate. The Pacific Plate is moving in a northwest direction at a rate of 5-8 cm per year, subducting (diving) under the North American Plate. The diving action of the Pacific Plate results in numerous earthquakes and contributes to the many active volcanoes in the region. Explosive volcanic eruptions, such as Katmai's Novarupta in 1912, can catastrophically disturb hundreds to thousands of square miles of landscape, profoundly affecting fluxes of water and sediment. Vegetation can be defoliated, buried, or removed; and the landscape can be mantled with tephra (airborne volcanic ejecta ranging from ash to small blocks of rock). Rivers and lakes can be partly or completely filled with pyroclastic debris, and massive deposits of debris avalanches and pyroclastic flows can overwhelm valleys.

During the 1964 Alaska earthquake, some portions of the Lake Clark and Katmai coastline subsided by more than six feet. To the east, uplift as much as 30 feet occurred seaward of the subsidence zone, which means a large expanse of land changed elevation significantly in just a few minutes. Since 1964, some of the sunken areas have rebounded, and others have been buried in silt. In addition, some coastal lands in this region are experiencing isostatic rebound caused by glacier retreat.

The tectonically active history of Southwest Alaska Network parks indicates that potentially catastrophic changes (e.g., major volcanic eruptions, major earthquakes) could occur in the future and have widespread effects on park ecosystems. These landscape-scale disturbances have the ability to modify landforms and reorder successsional processes. The slower, smaller changes in land height due to isostatic rebound are also important, especially for the coastal zone. Although the annual changes might be small (measured in millimeters), the changes accumulate over decades and up to centuries.

On the annual/decadal scale, smaller scale disturbances such as flooding, windstorms, landslides, and insect outbreaks can be major drivers of ecosystem structure and function. Fire, which is a major disturbance elsewhere in Alaska, is a rare event in SWAN parks. Fluvial processes, such as snowmelt and storm floods, can reconfigure channels, erode portions of the floodplain, and deposit sediment within and outside the floodplain. These disturbances can remove existing vegetation and create new islands, bars, or flats where soil and vegetation can develop.

Similarly, catastrophic winds (exceeding 100 miles/hour) cause large-scale forest blowdown in Lake Clark, Kenai Fjords, and portions of Katmai. Depending on intensity, they can create single-generation stands of trees with uniform canopies or multigeneration stands with diverse canopy and size structures. These catastrophic winds can affect site productivity through tree uprooting and subsequent soil churning,

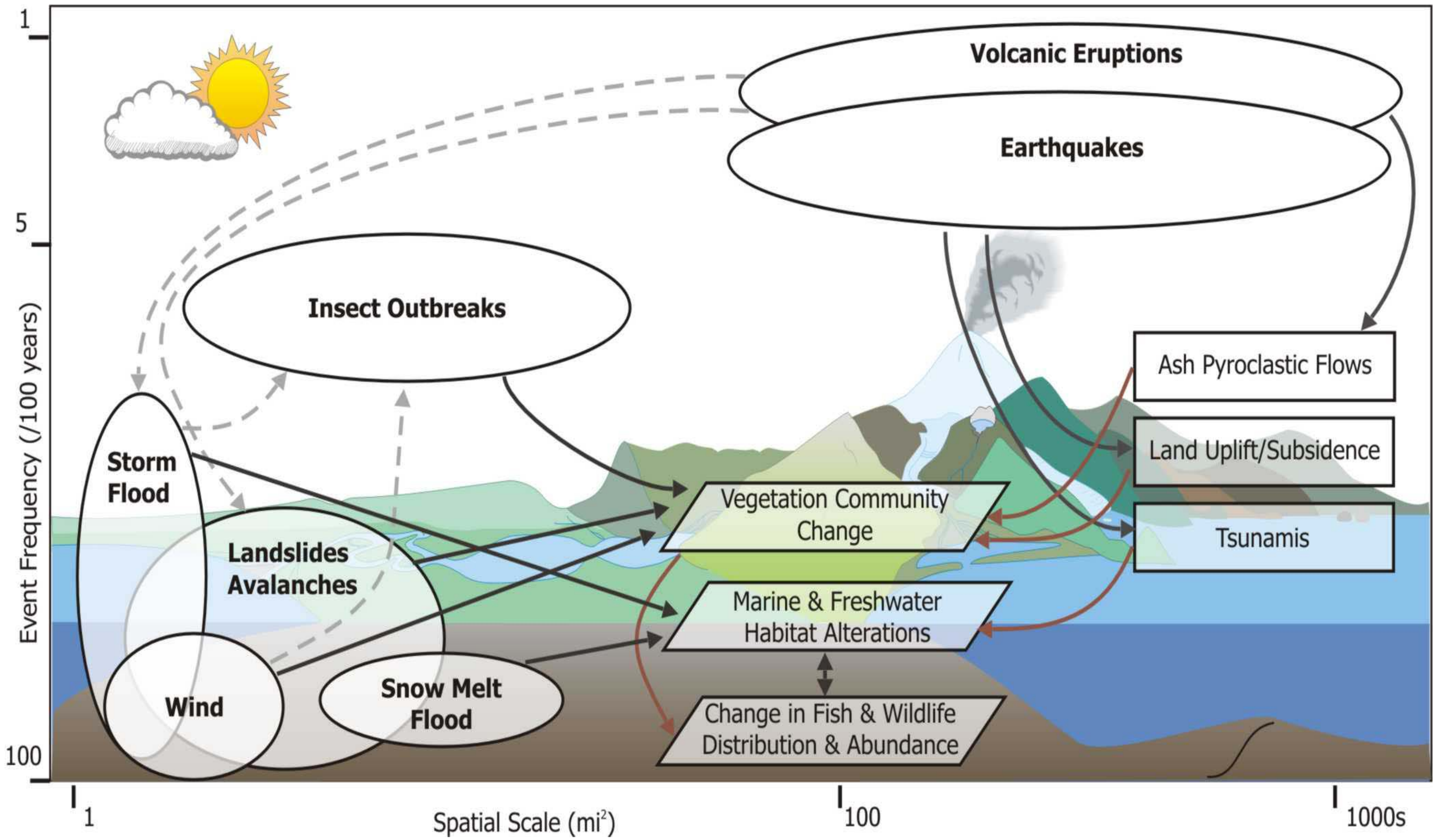


Figure 2-5. Landscape Disturbance Model. Frequency, scale, and consequences of natural disturbances in the Southwest Alaska Network. Large-scale disturbances (volcanic eruptions, earthquakes, tsunamis) and more frequent smaller-scale disturbances (insect outbreaks, floods, and landslides) create and maintain a shifting mosaic of landscape patterns.

exposure of mineral soil seedbeds, and create early successional stands favored by herbivores such as moose and snowshoe hares.

Landslides are common in coastal areas due to steep slopes, unstable substrate, and frequent rainfall. Landslides may cover a small proportion of the land area in network parks, but are important centers of biodiversity as they provide temporary refuges for pioneer species not found elsewhere. Landslides also promote downhill migration of nutrients and soil organic matter across the landscape.

The spruce bark beetle is the most significant natural mortality agent of mature spruce in Alaska, besides fire. Bark beetles are native species, and they play an important role in the ecosystem. For example, large-scale infestations have a significant influence on fish and wildlife habitats by changing their structure and function. Bark beetle-caused tree mortality provides important habitat for some species of wildlife, provides coarse woody debris to streams, and contributes to nutrient recycling. Outbreaks can also affect park management objectives, particularly in high-use recreation areas.

Large- and small-scale natural disturbances often interact to produce patterns of landscape change. For example, volcanic eruptions and earthquakes commonly trigger landslides. Most spruce bark beetle outbreaks in standing spruce originate in wind-thrown trees and emerge from this highly productive breeding material to move into standing trees. Hence, insect outbreaks originate and are most intense in areas prone to intense winds, such as Lake Clark Pass.

The SWAN is one of the few large landscapes on this continent where natural disturbance regimes exist relatively free from anthropogenic influence. Long-term monitoring presents a unique opportunity to determine the frequency, probability, variation, and patterns of disturbance and how plants and animals respond to changes in their habitat.

3. Biotic Interactions

Biotic interactions embody the “species concept” of landscape ecology discussed in chapter 1. Plants and animals regulate the flows of energy and nutrients in ecosystems through their consumption and digestion, as well as through their behaviors and death. Plants and animals also indirectly control these flows by regulating the population dynamics of other organisms with which they interact through competition, predation, herbivory, parasitism, mutualism, and commensalism. Because of the large number of interactions among species, we limit our discussion to interactions involving “keystone” species or those that affect multiple ecosystems (figure 2-6). Greater detail is presented in food web models for marine, terrestrial, and freshwater ecosystems (appendix G).

Wide-ranging species, especially those that influence water and nutrient dynamics, trophic interactions, or disturbance regime, affect the structure and functioning of ecosystems on broad spatial scales (chapter 1, section E). For example, brown bears influence coastal intertidal community structure when they forage on salt marsh vegetation and clams, transfer nutrients from rivers to the land when they feed on salmon (Ben-David et al. 1998; Hilderbrand et al. 1999a), and influence plant distribution and mineral availability when they dig in montane meadows (Tardiff and Standford 1998). Moose alter succession of the forest, soil chemistry, and even the number and type of insects found where moose live (Rozell 2002).

The influx of anadromous salmon dramatically affects the trophic structure and functioning of the freshwater community. Most salmon die after they spawn and their carcasses accumulate in streams and along lakeshores. A rich community of algae, fungi, and bacteria develops on the carcasses, and populations of invertebrates increase. These invertebrates then serve as food for fish in the streams and lakes, including juvenile salmon. More surprising are the potential fertilizer effects of salmon carcasses on land. Bears and other carnivores commonly haul salmon, living or dead, onto stream banks and hundreds of yards into the forest. Eagles move carcasses into riparian areas, and ravens and crows cache salmon bits in trees and under grass and rocks. Nutrients pass from the bodies of salmon into the soil and then into riparian vegetation and ultimately farther up the terrestrial food chain.

Large terrestrial herbivore-predator interactions are an intrinsic property of intact functioning ecosystems and are a ‘flagship’ ecological feature of network parks. Selective foraging by herbivores, such as caribou, can alter ecosystem functioning, change species composition, modify nutrient cycling and plant productivity. Wolves are functionally important in this interaction because they exert top-down control of herbivores. Because caribou and wolf populations oscillate through time, herbivore-predator population cycles play an important role in maintaining a heterogeneous distribution of resources or “habitat mosaic.”

In coastal ecosystems bivalve mollusks, such as mussels and clams, build thick shellfish beds and mats on rocky shores and soft sediments. The structure provided by these animal communities serves to modify the nearshore environment, deposits organic matter, traps sediments, and promotes growth of marine plants. In lagoons and tidal flats, mussels and clams form the primary prey base and influence the distribution and abundance of sea otters, sea ducks, shorebirds, and other birds and mammals. Marine plants, such as grasses and kelps, form canopies of vegetation that modify water flow, entrain larvae, and provide habitat and refuge for small fish and invertebrates.

Some biotic relationships involve species that do not directly interact with each other. For example, removal of sea otters from a coastal ecosystem can result in an irruption of sea urchins (the primary prey) that can lead to overgrazing and the

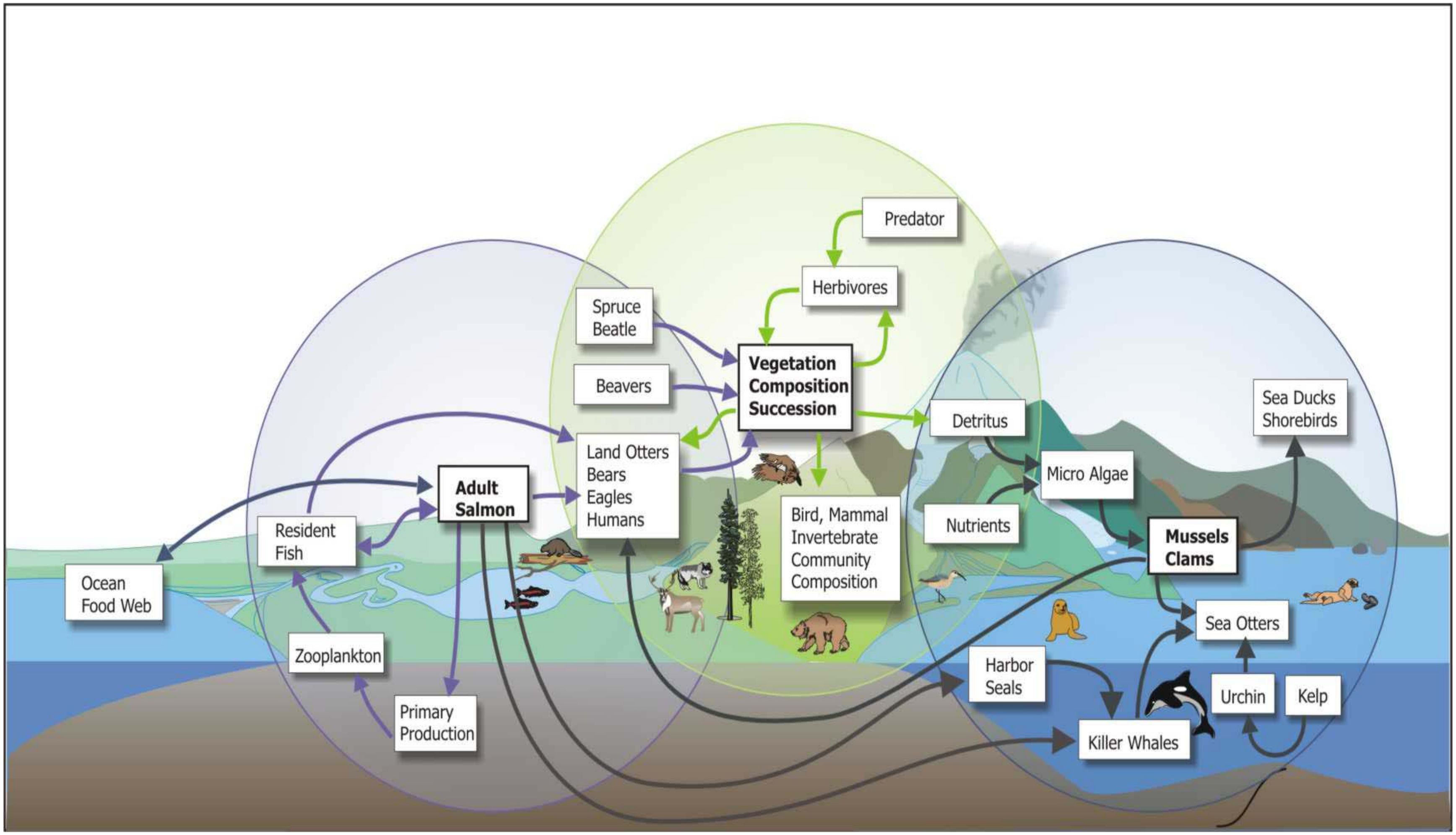


Figure 2-6. Biotic Interactions Model. ▪ Some important biological interactions in the Southwest Alaska Network involve the transport of nutrients by mobile species; ▪ herbivore-predator interactions that maintain a heterogeneous distribution of resources; ▪ “ecosystem engineers,” such as beavers and clams, that structure habitats and influence the distribution and abundance of other species; ▪ and species, such as the spruce bark beetle, that create or modify disturbance regimes.

subsequent decline of kelp. Natural and human-related actions that create imbalances in the most basic species interactions, especially predator-prey relationships, may result in changes in the composition and structure of communities and ecosystems.

Alder (*Alnus spp*) is a native plant that deserves special consideration in SWAN parks because of its life cycle characteristics, role in nitrogen-fixing, widespread distribution, and increasing abundance. Alder is a pioneer species that aggressively colonizes disturbed or newly exposed soil. Once established, it can also invade other vegetation types. Very few other plants can survive under the canopy of alder, and its foliage and stems are avoided by most herbivores. Thus, the presence of alder determines plant and animal communities, and it can play an important role in ecosystem dynamics.

4. Human Activities (Stressors)

Human activities are drivers that can act as stressors and are important agents of change in Southwest Alaska Network ecosystems. During our workshops, conceptual models of human activities were refined to show relationships and interactions among stressors (figure 2-7). For example, climate warming due to anthropogenic greenhouse gases could increase susceptibility of network parks to invasion by exotic plants and animals, and increased visitation of parks by visitors in floatplanes would be an important pathway for introduction of exotic species. Understanding the interactions among stressors was crucial to assessing pathways of change due to human activities. For this reason, we grouped stressors into two broad categories: far-field influences and near-field influences. As stated in chapter 1, far-field influences include human activities occurring elsewhere on the globe that could impact network ecosystems; and near-field influences include human activities occurring in or on lands and waters adjacent to parks.

Far-field Influences

The far-field human influences arise from human population growth and the general trend of human activities worldwide that might best be termed “global industrialization.” Effects of global industrialization generally fall into two categories: (1) effects on biogeochemical cycling, and (2) effects on biodiversity (Vitousek et al. 1997). For Southwest Alaska Network parks, biogeochemical cycling issues would most likely stem from changes in climate due to greenhouse gases and changes in atmospheric deposition patterns (e.g., pollution).

Climate change - Projections of human-induced climate changes and evidence of past rapid climatic shifts indicate that patterns of physical and biological change are occurring on landscape scales in time frames as short as decades (Hannah et al. 2002). Gradual warming documented in the last 100 years has

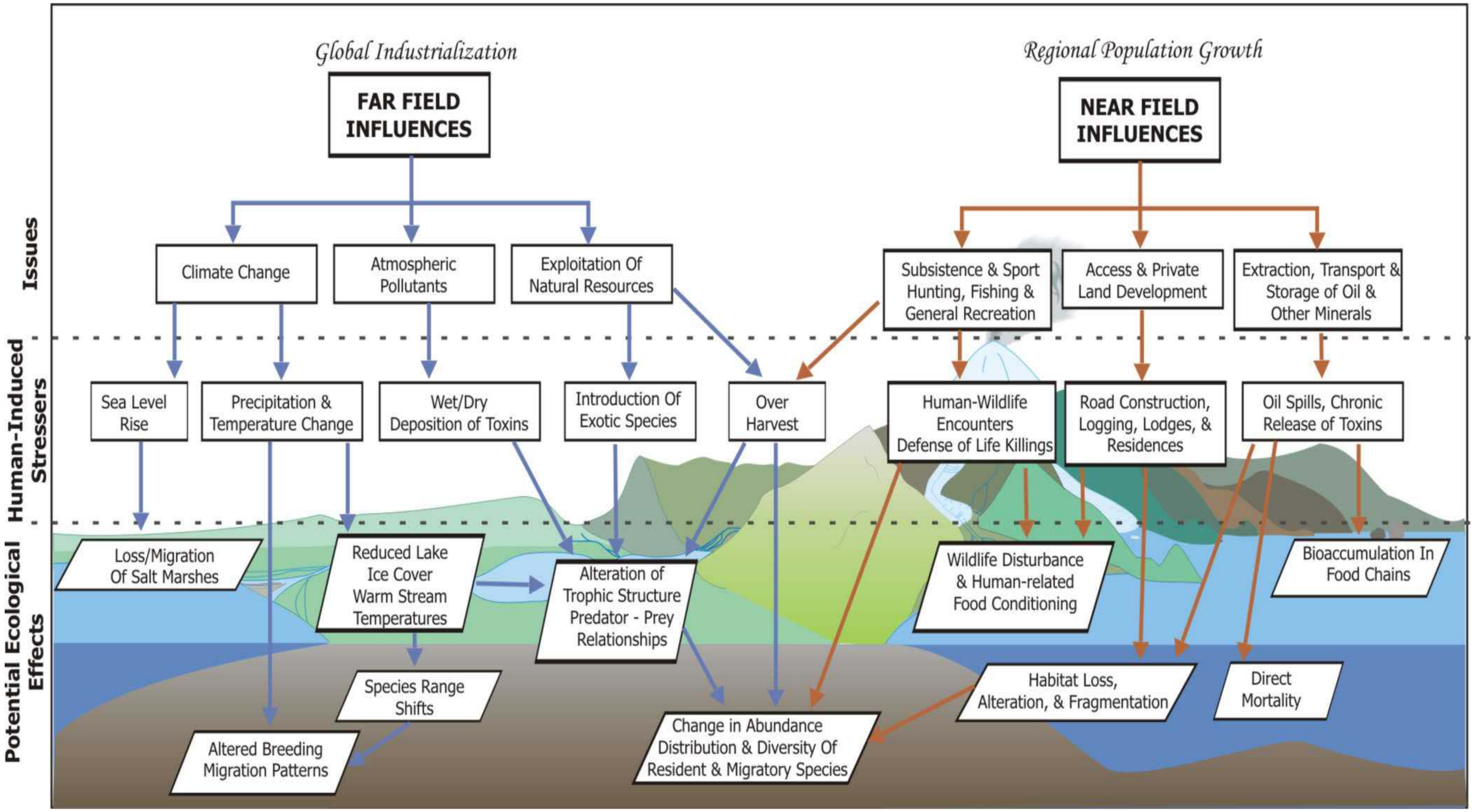


Figure 2-7. Human Activities Model. Far-field and near-field issues that act as stressors to affect ecosystems in the Southwest Alaska Network. Far-field human-related issues are manifested as climate change, long-distance air pollution, depletion of migratory species, and introduction of exotic species. . Near-field human-related issues are manifested as harvest of plants and animals, recreational use, private lands development, and the extraction, storage, and transport of oil, gas, and mineral resources in Bristol Bay and the Northern Gulf of Alaska.

forced a global movement of animals and plants northward, and it has sped up such perennial spring activities as flowering and egg hatching. In some cases, the shifts have been dramatic. For example, the common murre (*Uria aalge*) breeds 24 days earlier than it did decades ago (Meehan et al. 1998).

Climate-change-induced shifts in park ecosystems can be manifested in many different ways, on different temporal and spatial scales (figure 2-8). Some anticipated changes include sea-level rise, greater storm intensity and frequency, altered seasonal hydrology, accelerated glacial retreat, and shorter duration of lake ice cover. Changes in these physical parameters may not be important by themselves, but may have important effects on biological components of the ecosystem. Water availability in some regions (i.e., Bering Sea drainages) may decline because of a reduction in precipitation and because of reduced snow-pack and shorter snow season. Changes in snow amount will lead to significant shifts in the timing and amount of runoff in network river basins, most of which originate in mountains and uplands.

Along the Gulf of Alaska, warming has also been associated with an increase in precipitation of about 30% between 1969 and 1999 (Alaska Regional Assessment Group 1999). Coastal regions of SWAN may experience greater freshwater runoff from precipitation and accelerated melting of glaciers. Ultimately, runoff from the melting glaciers will cease and summer discharge will decline.

A warming climate has broad implications for park resources and long-term monitoring. As a result of a longer growing season and higher temperatures, montane alpine areas will shrink because of upward migration of tree species. Changes in temperature, precipitation, snow pack, storm frequency, and fire could affect the distribution, abundance, growth, and productivity of plants and animals. New populations of species may move into some areas and existing populations might move out or be lost. Some animal populations may become stranded and unable to adapt to changing conditions, or they may shift ranges as the climate to which they are adapted effectively moves northward or to higher elevations. Because anticipation of changes improves our capacity to protect park resources, it behooves us to increase our understanding about the responses of plants and animals to a changing climate.

Air pollution - Long-distance transport and deposition of air pollutants such as persistent organic pollutants (POP) is an emerging concern in Alaska national parks. POPs are organic, human-made, highly toxic compounds. They persist in the environment and bioaccumulate in living organisms. They are able to travel long distances around the globe and migrate to northern climates because of strong south-to-north air flows. The Arctic is, therefore, a potential contaminant storage reservoir and/or sink. Due to a constellation of different factors related to

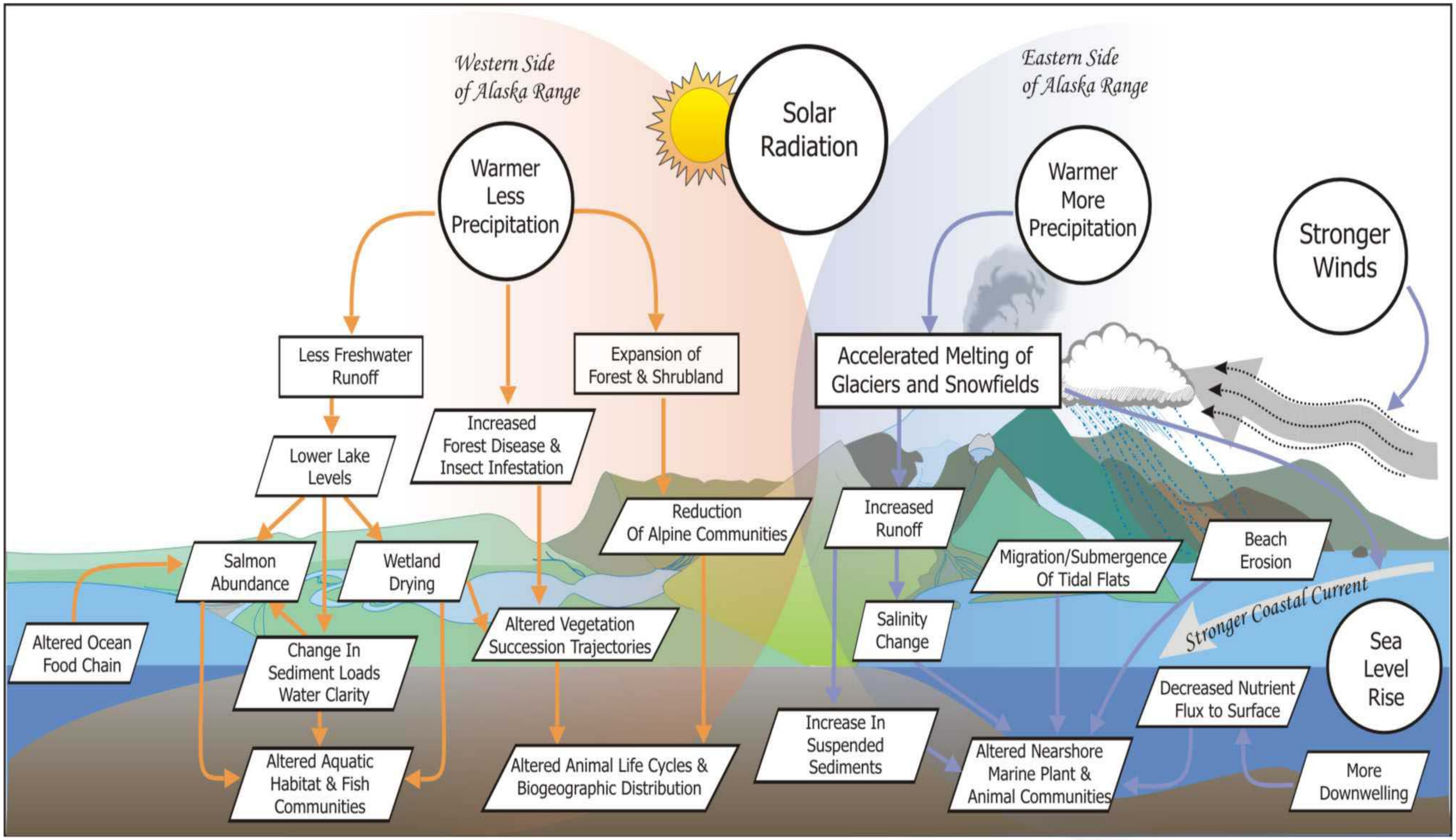


Figure 2-8. Climate Warming Model. Manifestations of a warming climate on Southwest Alaska Network ecosystems, habitats, plants, and animals. . Warming is likely to alter the hydrologic cycle in SWAN and influence processes that have created and maintained park ecosystems. Some anticipated changes include sea-level rise, greater storm intensity and frequency, altered patterns of seasonal runoff, rapid glacial retreat, and shorter duration of lake ice cover.

atmospheric patterns, the behavior of contaminants in the environment, temperature, and other factors unique to the Arctic setting, there is cause for concern regarding an increase in levels of contaminants in park ecosystems.

Various processes remove these contaminants from the atmosphere, oceans and rivers and make them available to plants and animals. Food chains are the major biological pathways for selective uptake, transfer, and sometimes magnification of contaminants by plants and animals. In Alaska contamination has been documented in the marine and freshwater food web (Kremmel et al. 2000; Ewald et al. 1998), but whether this contamination encompasses terrestrial animals to the same extent is unknown.

Exotic Species - Invited experts attending our scoping workshops emphasized the importance of not underestimating the potential for invasive species to act as stressors for Southwest Alaska Network parks. Their recommendations are in line with recent strong concerns about species invasions raised in the scientific community (e.g., Vitousek et al. 1997, Mack et al. 2000). The State of Alaska has recently adopted an Aquatic Nuisance Species Management Plan (Alaska Department of Fish and Game 2002). This plan identifies the most important species of immediate concern for Alaska (appendix J).

Of particular concern for the Southwest Network is the potential for Northern Pike (*Esox lucius*) to expand from the Susitna River drainage basin southward to western Cook Inlet, where they are not indigenous. Pike prey on small salmon and trout and have the potential to restructure fish communities. An even greater threat is Atlantic salmon (*Salmo salar*) that escaped from aquaculture sites in British Columbia and Washington. This invasive species may compete with native Pacific salmon for spawning and rearing habitat. For the Southwest Alaska Network, the main pathways of introduction are likely those that involve recreational fishing and aquaculture.

Although SWAN parks are currently assumed to be free of aquatic nuisance species, the same cannot be said of the invasive plants in the terrestrial environment. Inventories of exotic plants in selected national parks in Alaska have been conducted recently (Densmore et al. 2001). In the road-accessible Exit Glacier area of Kenai Fjords and in areas of constant human use at Katmai, Densmore et al. (2001) found several exotic weeds. Densmore et al. (2001) concluded that the parks most vulnerable to invasion by exotic plants are those, such as the Southwest Alaska Network, with moderate maritime climates.

Migratory species - Another driver of change related to global issues concerns effects on migratory species when they are not in SWAN parks. The North Pacific and Bering Sea are among the most important seas for commercial salmon fisheries in the world. Depletion of salmon on the high seas could result in lower return rates to the parks with cascading effects in these salmon-based ecosystems. The rates of spawning, growth, and mortality in salmon populations are also influenced by changes in the marine environment. The fish stocks are sensitive to ocean temperatures, and small changes can result in major shifts in the geographic locations and productivity.

Migratory birds use network parks for breeding and migration and may play important ecological roles as prey or predator. For example, Rock Sandpipers (*Calidris ptilocnemis*) that breed on the Pribilof Islands winter in Cook Inlet and forage on coastal intertidal flats at Lake Clark National Park. Of the more than 150 bird species known from these parks, the majority are migratory. These species could be affected when they are at their wintering grounds in the offshore waters of the North Pacific, the continental U.S., Mexico, Central and South America, the South Pacific, and Asia.

Near-field Influences

The main types of near-field, human influences with potential effects on SWAN parks include regional population growth, and exploration and development of oil, gas, and mineral resources in the Cook Inlet region (figure 2-7). Other near-field influences relate more specifically to human activities in parks. These include visitor use impacts, private land development in and near parks, and consumption of fish and wildlife. Collectively these form the common theme of “access.”

A concept that is particularly useful for viewing park protection concerns related to near-field human activities is the “*nibbling effect*” (Forbes et al. 2001). This concept maintains that a slow but essentially permanent change in ecosystem structure, components, and processes occurs from many seemingly “insignificant” human-related perturbations. Examples of *nibbling* include the liberalization of sport or subsistence harvest levels for a plant or animal, construction of a new airstrip or commercial lodge on a private inholding within a park, or issuance of 10 new incidental business permits for guided backcountry hiking. Alone each “bite” may appear relatively insignificant, but collectively they have a cumulative and synergistic effect. *Nibbling* advances slowly through space and time and often along gradients radiating from rural population centers, such as Port Alsworth on Lake Clark, or attractions, such as Brooks Camp on Katmai’s Naknek Lake (figure 1-2).

Oil and other minerals - Extraction, storage, transport, and processing of crude oil is an issue for both coastal and terrestrial resources. The Valdez Marine Terminal on Prince William Sound receives approximately 14 billion gallons of oil per year via the Trans Alaska Pipeline System. Also, 15 oil production platforms are operating in Cook Inlet. The Drift River Marine Terminal is a privately owned offshore oil-loading platform in Cook Inlet with an onshore storage facility whose capacity is 1.9 million barrels (79.4 million gallons) of crude oil. The Nikiski Oil Terminal and Refinery are located on the eastern shore of Cook Inlet. These two oil-loading facilities transfer more than 3.3 billion gallons of oil per year.

The strong Alaska Coastal Current and high local tidal ranges along the Alaska coast can quickly transport spills great distances from their source. On March 24, 1989, the tanker vessel *Exxon Valdez* grounded in Prince William Sound, rupturing cargo tanks and spilling approximately 11 million gallons of crude oil into the sea. The coastlines of Kenai Fjords, Katmai, and Aniakchak were oiled by this spill. Industrial practices have improved since the spill; and transport of North Slope crude oil via tankers in Prince William Sound still occurs, so the potential for additional spills exists. Clean up of the *Exxon Valdez* oil spill introduced people to the Katmai and Kenai Fjords coastlines, and increased subsequent public use, demonstrating an unanticipated interaction between stressors.

Smaller spills; leakage from storage tanks, platforms, and submerged pipelines; and ballast water discharge in Upper Cook Inlet are chronic sources of contamination. The water resources of network parks also are threatened by the potential exploration and development of oil and gas in Lower Cook Inlet and Shelikof Strait under the Outer Continental Shelf program.

Consumptive harvest of plants and animals by humans - Consumptive uses of plants and animals is permitted in Lake Clark, Aniakchak, and portions of Katmai under the Alaska National Interest Lands Conservation Act (ANILCA). This act allows for hunting, trapping, fishing, and the harvest of plant material in national parks and preserves and for subsistence uses by local rural residents. In national parks and preserves, ANILCA also requires the National Park Service, in cooperation with the Alaska Department of Fish and Game, to manage for healthy populations of fish and wildlife species in national preserves, and natural and healthy populations in national parks. Additionally, sportfishing occurs in parks and preserves and sporthunting occurs in preserves.

Although subsistence users have access to all species that were traditionally harvested, most effort is directed at large terrestrial mammals (moose, caribou, Dall sheep, brown bear), harbor seals, and salmon. Monitoring the harvest rate and population performance of subsistence resources is a complex challenge that frequently exceeds the capability of park managers. As a result, relationships between recruitment, annual survival, and harvest rate for many subsistence species are unknown; and local overharvest, if it occurs, may go undetected. In Alaska, the state constitution mandates that state resources be managed for maximum sustained yield. The concept of game naturally cycling between scarcity and abundance is not favorably embraced by subsistence users who desire a steady supply of resources. Of concern in recent years is a growing opinion by subsistence users that parks and preserves should also be managed for maximum sustained yield of fish and game resources.

Recreational Use - Human recreational use presents two resource protection issues: (1) direct impact to physical resources, plants, and animals from actions such as vehicle use and camping, and (2) indirect impacts, such as the disturbance or displacement of wildlife from actions like aircraft overflights. Coastlines, lakeshores, riverbanks, and high mountain environments are particularly sensitive to the disturbances caused by recreational use. Vehicle traffic, trampling by pedestrians, and campsites can create long-lasting impacts because natural recovery is extremely slow. As visitation increases, pressure builds to provide new trails or access opportunities into these large wilderness parks. There is also a very strong push to make these very large wilderness parks more accessible by ground transportation.

Human visitor concentration areas adversely affect animals as evidenced by human-related food-conditioning , displacement, and introduction of exotic species. Habituation is a threat to species such as bears that may have to be relocated or killed if they lose instinctive fear of humans. Disturbance adversely affects species if they are displaced from habitat during a critical phase of their life cycle, such as breeding. Bear viewing and photography from both small fixed-wing aircraft and charter boat tours have increased greatly in the last decade in SWAN parks. These activities have the capacity to disturb bears and other wildlife over wider regions than fixed-point activities like camping and fishing.

Human traffic into wilderness enhances the opportunity for exotic plants and animals to reach remote areas of the parks where they could go undetected. Avenues of entry include marine charter vessels that originate in the same Alaska harbors served by trans-oceanic cargo ships and floatplanes that originate in commercial floatplane bases, such as Lake Hood in Anchorage.

Private lands development - All parks in the network contain private land inholdings and border private, state, and Native-owned lands. Inholdings range from 1-160 acre parcels owned by an individual or a single business, to large contiguous parcels (>10,000 acres) that are owned by Native regional and village corporations. The network of private inholding arose from ANILCA, Alaska Native Claims Settlement Act (ANCSA), and the Homestead Act. Collectively these acts guarantee access and the promised right of communities, landowners, and residents to continue their economic livelihood.

Inholdings are most prevalent in Lake Clark and Kenai Fjords. In Lake Clark National Park and Preserve approximately 617,000 acres are in private or state ownership or are being adjudicated. This includes approximately 75 percent of the shoreline of Lake Clark and more than 90 percent of the park's Cook Inlet coastline. At Kenai Fjords, private economic development potentially could occur on 42,000 acres of predominantly coastal land owned by Port Graham Native Corporation. In some cases, the exact land status is clouded by over-selection, selection by more than one entity, and the incomplete adjudication of many small tract entries and allotments.

Residential subdivision and economic development on private lands in network parks can conflict with the enabling legislation and NPS resource preservation objectives. Developments of greatest concern are logging, mining, and the construction of roads, airstrips, lodges, and private houses. Private land inholdings frequently coincide with areas of great ecological value and sensitivity such as rivers, lakeshores, and coastal estuaries. Consequently, large areas of parkland adjacent to inholding are at risk when development occurs. Most concerns of water quality are imbedded in private land development.

Access - Access is a common theme among near-field influences. Access concerns include the landing and beaching of floatplanes on lake shores and riverbanks, landing of wheeled planes on beaches and gravel bars, beaching of boats, concentrated camping sites associated with boating, and use of all-terrain and 4-wheel drive vehicles off roads. Access methods may involve disturbance of fish and wildlife and disruption of habitat and may provide the means for overharvest, poaching, and defense of life and property killings.

Because some network parks are surrounded by private lands, it is not inconceivable that they could become “islands in space,” as are many parks in the continental U.S. For example, the historic Pile Bay Road between Iliamna Bay on the Cook Inlet side of the Alaska Peninsula, and Lake Iliamna, has been upgraded to provide for year-round traffic and is targeted for future improvements. The road will be heavily used by local residents, mining industries, commercial fishermen, and to support new tourist activities. It is likely to support regional population growth between Lake Clark and Katmai. In 2003, the State of Alaska allocated $10 million to study road development, including the construction of a 182-mile road linking King Salmon and Chignik on the Alaska Peninsula (figure 1-2).

C. Ecosystem Interactions

The nature of SWAN parks is largely determined by the complex and dynamic physical, geological and chemical inputs and interactions of marine, aquatic, and terrestrial subsystems. Therefore, a basic understanding of atmosphere-land-ocean interrelationships is important for us to comprehend how physical and biological drivers influence ecosystems. Ecosystem connectivity is a key feature of the network and is particularly important because connectivity is one of the first attributes to be affected by natural disturbances, such as a volcanic eruption, or human activities, such as the construction of a road. Some of the critical linkages involve water movement (figure 2-9), heat exchange, sediment and nutrient transport, and the actions of producers and consumers.

Storage and release of snow pack is pivotal in regulating linkages between the land surface, ocean, and overlying atmosphere. During the winter, higher elevations of the coastal mountain ranges collect and store large amounts of snow. During the thaw season, water runs off, transporting mass and energy through watersheds and into the Pacific Ocean and Bering Sea. This cycle recharges lakes and wetlands though runoff and transports sediments and other constituents to the ocean where it affects nearshore physical and biological productivity. Freshwater input to the ocean also maintains and regulates the Alaska Coastal Current, which in turn influences nutrient and thermal dynamics of nearshore bays and fjords.

Figure 2-9. Precipitation falls on the land; water flows over the landscape; and it carves channels that carry water, nutrients, and sediment to other larger water bodies, and eventually to the ocean. In the process, water links ecosystems and creates habitats that form the biophysical foundation for living communities in the Southwest Alaska Network, including those of humans.

Changes in snow cover area and dynamics regulate thermal exchange between the land and atmosphere and influence faunal and floral distributions on land and water. Consequences resulting from alterations to surface water movement and storage include: changes in flooding timing and duration, changes in flow regime, and changes in surface water storage capacity.

Freshwater systems result from the regional pattern of precipitation interacting with topography and surficial geology (figure 2-10). The topography and geology are important for determining the gradient of streams and the configuration and depth of lakes. Most freshwater flow systems in the network are currently of glacier origin. Permanent and ephemeral streams link glaciers and lakes during the summer melt season. These glacial meltwater streams recharge the dry valley lakes and are important sources of nutrients and materials to lake ecosystems. Distinct seasonal runoff patterns caused by the annual cycle of snow and ice melt change the hydrological connectivity between individual stream types and shift flows from surface dominance at summer high flow to groundwater controlled in winter.

Lakes in the SWAN are created by a variety of processes, including volcanoes, glacial retreat, fluvial processes, and beavers. Most lakes that are important salmon spawning and rearing grounds occur in glacial landforms. Because of their large surface areas, wind is a significant factor, affecting productivity dynamics. The food base in these lakes is based on phytoplankton and zooplankton, but nutrient input from salmon carcasses may plan an important role. Volcanic ash inputs to these lakes may also contribute to their high productivity.

An important concept that emerged from the freshwater scoping workshop is the principle that lakes and streams comprise interconnected flow systems within the broader landscape. As collectors of water, energy, nutrients, solutes, and pollutants from the landscape and atmosphere, lakes and streams are interactive components of their environment. The flow system concept helps show relationships between the land and water and is important for understanding regional connectivity in ecosystem pattern and function.

The nearshore coastal ecosystem of SWAN is influenced by a host of factors, both upland/upriver processes and marine processes, both natural and anthropogenic, due to its linear configuration and proximity to coastal mountains. Factors that affect oceanic, freshwater, and terrestrial systems individually seemingly coalesce in a “great mixing bowl” to influence the coastal nearshore.

Coastal streams gather material from large land areas and concentrate them in estuaries at the land-sea ecotone. Consequently, inshore ecosystems and coastal ecosystems are functionally linked at multiple levels by movements of material and nutrients as sea water is mixed with freshwater. SWAN terrestrial and coastal communities are characterized by overlapping food chains as energy flows from primary producers to consumers (appendix G). Many primary producers are first converted by bacterial decomposition into organic detritus, which serves as a major food source for the majority of consumers living in intertidal flats and estuaries. Carnivores (predators) occupy the highest level, obtaining energy by eating animals that feed on plankton and detritus.

In addition to inputs from the land, a variety of oceanographic processes bring cold, nutrient rich water into the nearshore zone from offshore. These forces include wind-driven transport, tidally driven transport, and buoyancy-driven transport, such as the Alaska Coastal Current. The Alaska Coastal Current is an ever-changing feature offshore that plays many important ecological roles. For example, it supplies plankton to bays and estuaries and carries fish and invertebrate eggs from one place to another. The success of many species depends on the specific shape of the current, which is influenced by climate, season, and sea floor topography. In some coastal areas of Kenai Fjords and Katmai, locally rich habitats and plant and animal communities develop in areas where food supplies are concentrated by eddies and circular side currents that form as larger currents move around landmasses.

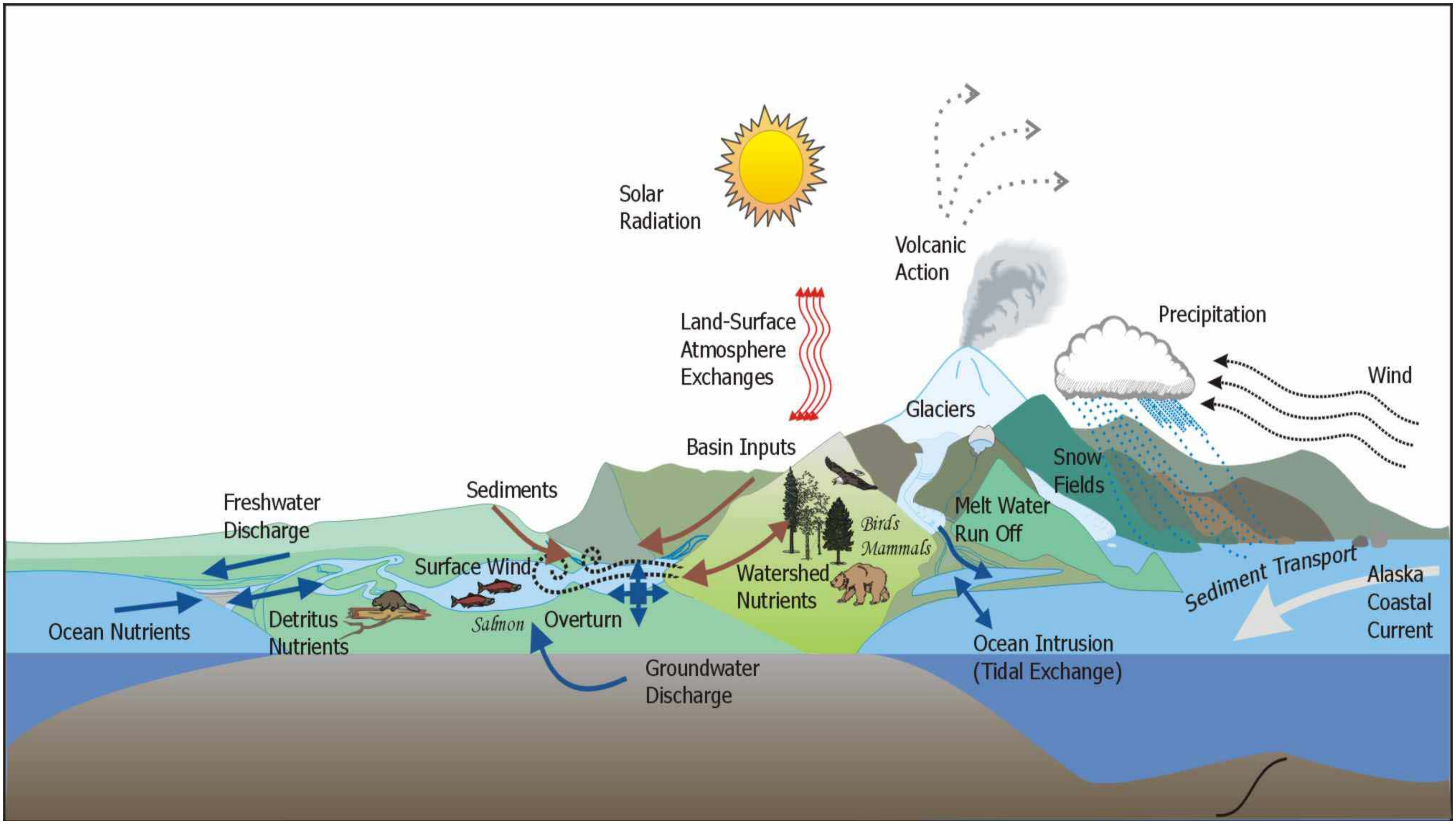


Figure 2-10. Ecosystem Interactions Model. Key linkages and interactions between the atmosphere, ocean, and land in the Southwest Alaska Network. Hydrologic and biochemical interactions with terrestrial and aquatic ecosystems control the formation of habitats and distribution of plants and animals.

Heat given off by the oceans warms the land during the winter, and ocean waters help to keep coastal regions cooler during the summer. Moisture evaporated from the oceans is the ultimate source of precipitation on land. Topographic features of the land interact with the atmosphere to create meso scale regimes of temperature and wind. This interrelationship controls phenomena such as duration of lake cover, localized patterns of snow accumulation, and distribution of plants and animals. Sea level exerts a major influence on the coastal zone, shaping barrier islands and pushing salt water up estuaries and into aquifers.

Mobile biological organisms also transport matter and nutrients between systems. Leaves from riparian vegetation fall into streams and provide nutrients for the freshwater subsystem. Salmon returning to spawn in their natal streams bring marine nutrients to the terrestrial and freshwater subsystems. Bears, river otters, and other consumers transport salmon from the freshwater subsystem to the terrestrial and are the primary pathway for marine nutrients to enter the terrestrial subsystem. Similarly, birds and mammals consume intertidal marine resources, such as clams and fish, and transport nutrients from the ocean to the land. These interrelationships underscore the importance of not simply viewing ecosystems singularly, but that we also look across the landscape to understand how systems interact.

D. Conclusions

Conceptual models explain our understanding of landscape-scale drivers and ecological interactions and how they may affect selected natural resource processes and components of the SWAN parks. The point of preparing and presenting these conceptual models is to: 1) BEGIN the discussion of the attributes, functions, and linkages described by the models; 2) assist in the formulation of specific monitoring questions and hypotheses; and 3) provide a basis for identification and selection of ecological vital signs for long-term monitoring.

Climate interacts with landform to influence ecosystems through patterns of temperature and precipitation and the hydrologic cycle, which affects both aquatic and terrestrial plants and animal communities, as well as the physical processes within the landscape. Climate influences are strongly tied to conditions in the North Pacific, especially location and strength of the Aleutian Low winter storm system and the shift in storm track direction that occurs in summer. Various broader scale influences (i.e., things happening at the poles and in the tropics) affect how these annual patterns play out in longer time scales. Climate drives the timing and amount of water entering SWAN ecosystems and is a determinant of fundamental properties of the ecosystems. Climate within the network, although dominated by maritime influence, is not uniform due to topography and the network’s particular location relative to the annual shift in storm track direction.

Infrequent large-scale natural disturbances (volcanic eruptions, earthquakes, tsunamis) and more frequent smaller-scale disturbances (insect outbreaks, floods, landslides) create and maintain a shifting mosaic of landscape patterns. The tectonically active history of Southwest Alaska Network parks indicates that potentially catastrophic changes (e.g., major eruptions, major earthquakes) could occur in the future and have widespread effects on park ecosystems. These major-event, landscape-scale disturbances have the ability to set the clock back on the landscape and set in motion successional processes.

Many biotic interactions important as potential agents of change in network parks involve trophic relations among species. Salmon act as a keystone species, and changes in salmon runs and their timing could affect the structure and function of network ecosystems. Wide-ranging species—especially those that influence water and nutrient dynamics, trophic interactions, or disturbance regime—affect the structure and functioning of ecosystems on broad spatial scales.

Human far-field influences related to global industrialization are drivers of change the network needs to keep in mind for several reasons. Some changes in park ecosystems may be explainable only with a broader perspective (e.g., global climate changes), and focusing only on changes due to regional or park-specific threats might overlook threats with even greater potential to disrupt park ecosystems (e.g., invasive species). Near-field influences with the potential to drive change in network parks act very similarly in their effects. These near-field influences act primarily through their effects on fish and wildlife populations and habitats. Most visitor use, private development, fish and wildlife harvest, and access concerns relate to disturbance of fish and wildlife during critical life history phases, destruction or fragmentation of habitats, and overharvest. The other near-field influence, regional oil and gas development, would drive change through oil spills, which also act to disrupt fish and wildlife and their habitats.

Ecosystem connectivity is an important feature of the SWAN landscape. Some of the critical linkages involve water movement, heat exchange, sediment and nutrient transport, and the actions of producers and consumers. Climate, landscape-scale disturbance, biotic interactions, and human activities are drivers of change having the greatest relative impact on network parks. These drivers control the structure and processes in coastal, freshwater, and terrestrial ecosystems.